Certifiable Database Generation for SVS

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ABSTRACT

In future aircraft cockpits SVS will be used to display 3D physical and virtual information to pilots. A review of prototype and production Synthetic Vision Displays (SVD) from Euro Telematik, UPS Advanced Technologies, Universal Avionics, VDO-Luftfahrtgerätewerk, and NASA, are discussed.

As data sources terrain, obstacle, navigation, and airport data is needed. Jeppesen-Sanderson, Inc. and Darmstadt Univ. of Technology currently develop certifiable methods for acquisition, validation, and processing methods for terrain, obstacle, and airport databases. The acquired data will be integrated into a High-Quality Database (HQ-DB). This database is the master repository. It contains all information relevant for all types of aviation applications. From the HQ-DB SVS relevant data is retrieved, converted, decimated, and adapted into a SVS Real-Time Onboard Database (RTO-DB). The process of data acquisition, verification, and data processing will be defined in a way that allows certification within DO-200a and new RTCA/EUROCAE standards for airport and terrain data. The open formats proposed for the HQ-DB and RTO-DB can be used to exchange data on different abstraction levels. The complete process will be established and evaluated for industrial usability.

Finally, a NASA-industry cooperation to develop industrial SVS products under the umbrella of the NASA Aviation Safety Program (ASP) is introduced. A key element of the SVS NASA-ASP is the Jeppesen lead task to develop methods for world-wide database generation and certification. Jeppesen will build three example airport databases that will be used in flight trials with NASA test aircraft.

Keywords: Databases, SVS

1. INTRODUCTION

Today's commercial transport aircraft cockpits usually contain an electronic Primary Flight Display (PFD) and Navigation Display (ND) in front of the pilot. In General Aviation (GA) aircraft traditional round dial or "clock" instruments such as artificial horizon, speed indicator, altitude indicator, and variometer are available.

In addition to these conventional instrumentation, a SVD depicts a 3D perspective image of surrounding terrain[7,9,13] and airports[26]. Virtual information such as a "tunnel in the sky" or a landing channel can be integrated[5] as well. A Synthetic Vision System consists of three key elements[10].

A navigation unit must generate accurate and reliable position information[18,4]. The database has to contain all information displayable to the pilot. The database error must be in the same error class as the navigation information[3].

2. SYNTHETIC VISION DISPLAYS

Synthetic Vision Displays can be grouped into 2D and 3D displays. Most 3D depictions show a virtual world from the pilot's viewpoint (inside-out) on head down displays (HDD). A 2D display usually shows the virtual world from an infinite position above the earth (bird's eye view). The basis for SVD are mostly conventional 2D PFD/ND glass-cockpit symbology. This classical flight guidance information is overlaid by physical geo-spatial data. It incorporates digital terrain, terrain contour lines, obstacles, and airport information. Some system attach photo-textures to the terrain in order to create a photorealistic view of the surrounding environment. To enhance positional awareness virtual navigation data is overlaid. Flight paths data is rendered in most systems as a tunnel in the sky. Navigation aids are depicted with conventional symbology known from paper charts.

2.1 Euro-Telematik: 2D-Flight Guidance Displays

This unit, which provides Terrain Awareness Warning Systems (TAWS) functionality coupled with Moving-Map for basic navigation situational awareness is an example of a General Aviation/Corporate product, that combines a number of SVS features, using Commercial Off The Shelf (COTS) architecture, at a cost level traditionally associated with GA avionics.

The terrain is provided for defined geographical areas, such as Europe or the United States, and is displayed in 2D projections. The entire, self-contained unit fits in a double-height panel installation, that is appropriate for GA and Corporate aircraft.

Figure 1. Euro-Telematik GCAS-200

So, in describing this in terms of a SVS, the Display is self-contained (see Figure 1) , the navigation is provided by GPS position-sensing in the conventional fashion, either internal or external, and the database of terrain has been commercially acquired from Jeppesen.

2.2 UPS (Apollo): 2D-Flight Guidance Displays

This system, which provides TAWS functionality coupled with Moving Map for navigation situational awareness is an example of a SVS with a broader array of features (see Figure 2). Unlike the previous example, this system is comprised of several discrete components, where the SVS display and terrain database are in the MFD module, and the Navigation information is provided by an internal or external unit.

Figure 2. Apollo MX20 Multi-Function Display

The internal architecture also is based on COTS components, and is in the process of DO-178 (b) certification. The number of display modes include Terrain Awareness, VFR navigation, IFR navigation, and Stormscope/Lighting Strikes. The overall functionality is increased, by adding the ability for the pilot to customize, within certain guidelines, different views of the map information, with differing levels of detail and information presented.

The terrain database has been commercially acquired from a variety of sources, and is capable of supporting a variety of resolutions, from 3 arc-second up to 30 arc-second.

This unit is constructed as a member of a full set of avionics (known as a "radio stack"), and as such is able to graphically depict a number of tabular and graphical information sets. As such, this modular architecture will be easily adaptable to future developments in those other components of the radio stack, such as higher resolution terrain, obstacles, in-flight weather, etc. This would support the blending of real-world data, geo-spatially overlaid onto Synthetic Vision.

2.3 Universal System-1: 3D-Flight Guidance Displays

Universal Avionics has implemented SVS capabilities in their new Universal Cockpit Display (UCD-1) (see Figure 3). This is a component of an integrated avionics suite, that is fully connected with their Universal Flight Management Systems (FMS). Information from the FMS is used to render a number of 2D and 3D synthetic vision displays, and to also support the display of Jeppesen terminal charts on the UCD-1. Based on waypoint and flight plan information from the FMS, the appropriate chart can be displayed on the UCD-1 as required by the pilot. This system has a number of components, including the FMS, the TAWS unit, high resolution flat panel integrated displays (FPID), and the UCD-1.

Figure 3. Universal UCD-1

2.4 Rockwell-Collins: PRO-LINE 21

The new PRO-LINE 21 is an example of a fully integrated avionics suite, that provides all of the SVS-like capabilities directly in the PFD and ND (see Figure 4).

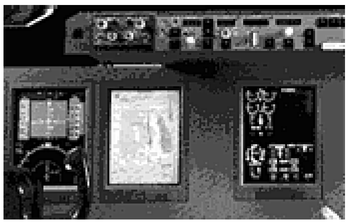


Figure 4. PRO-LINE 21 PFD and ND

It represents both 2D and 3D flight mode depictions, and has fully integrated TAWS and terminal chart display functionality. This systems also will support low-visibility surface movements, by displaying aircraft position on a geo-referenced airport diagram depicted on the ND. Unlike some of the other systems, this is not a secondary or supplemental information system, but rather more of a primary navigation display, which supports a number of SVS-like features.

2.4 VDO: 3D-Flight Guidance Displays

The VDO Luftfahrtgerätewerk developed together with Darmstadt Univ. of Tech. a combination display consisting of a 3D PFD and a 2D ND[6,9](see Figure 5 and 6). In the PFD conventional 2D Airbus symbology is overlaid by terrain, obstacle, and airport data. Virtual approach channels and 3D navigation aids are depicted. The predictor consists of eight small boxes flying in front of the aircraft. It shows the potential aircraft position in 4,8, and 12s. In combination with the depiction of the flight channel it forms a natural guidance cue. The terrain in the background enhances situational awareness by showing the pilot dangerous terrain in the vicinity of the aircraft. Terrain above the current aircraft position is depicted in red.

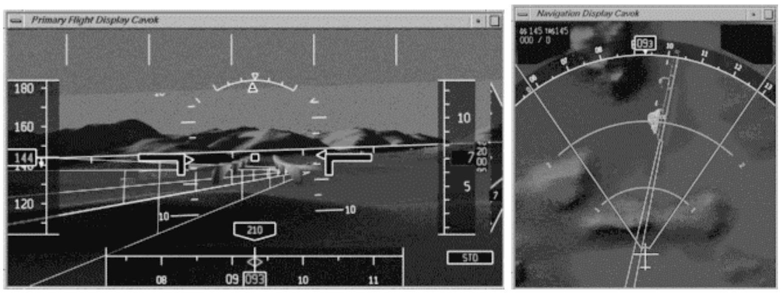


Figure 5. VDO/DUT Flight Guidance Displays[9]

The ND depicts terrain, obstacles, rivers, an major city outlines for long term tactical decision making[16]. Other aircraft can be shown if positional information is available via MODE-S or ADS-B. On the ground also a detailed vectorized moving airport map is available. It displays runways, taxi-way, and parking position names.

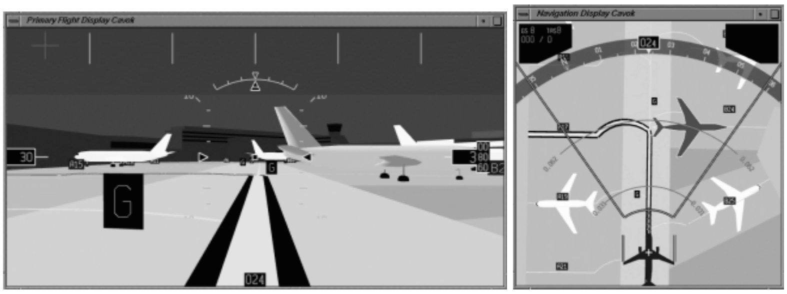
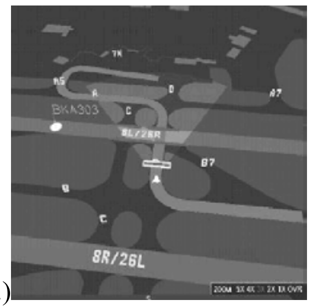


Figure 6. Taxi Guidance Display[16]

The taxiway from the runway exit to the destination gate are rendered as a thick yellow and black line for taxi guidance purposes. Especially on the ground the ND allows significant cost reduction by decreasing required taxi-times, reducing taxi errors, and an enhanced operational envelope[16]. Numerous taxi and in-flight test campaigns with the 30-seat jet ATTAS (VFW614) from the German Aerospace Center DLR took place in Braunscchweig and Frankfurt[8]. It was possible to demonstrate SVS usability for mountainous terrain awareness, standard approaches, and taxi guidance[8,24].

2.5 NASA: t-NASA

NASA developed a HDD and head up display (HUD) for taxi guidance operations (see Figure 7a). On the HUD virtual cones are rendered at the taxi-way edge and small virtual bars are visible on the taxi-way centerline. Together they form a natural guidance cue that outlines the desired taxi path of the aircraft[27]. Under extreme low visibility conditions (e.g. smaller than 75m) this overlaid airport symbology might become in the future the sole mean of navigation on insufficient equipped airports[26]. In taxi tests in the simulator and a NASA B757 the HUD reduced the pilot induced deviations from the optimal taxi path significantly[27]. On the HDD display a bird's eye view of the airport is shown (see Figure 7b and c). It renders buildings, runways, taxiways, the desired taxi-path to the gate, and the own aircraft[27]. The area covered by an out of the window view is shown as a light colored cone. The visible cone is a simple cue for the pilot to locate himself in the virtual scene on the display. Other aircraft, that have appropriate position reporting devices, can be depicted as well to reduce runway incursion and surface accident risk[27].

a.)  b.) 

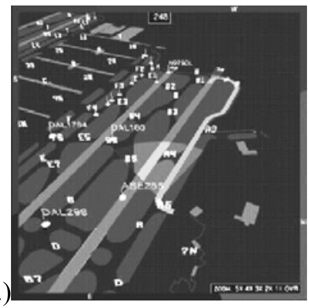
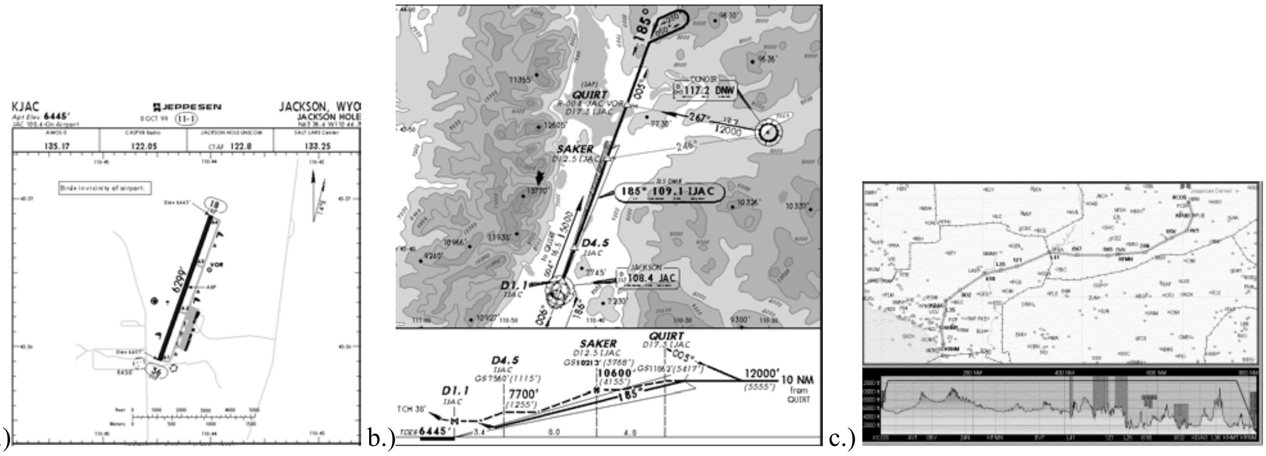
c.) 

Figure 7. t-NASA Visual path on HUD (a) Airport Map (b)[26]

In addition to the desired flight-path, red hold short bars are added. They are removed after Air Traffic Control (ATC) clears the runway. HUD and HDD-SVD were evaluated in taxi tests and flight trials in Atlanta, GA[26]. They were able to increase taxi guidance accuracy and to increase pilot positional and situational awareness. In 2000 tests will be conducted in Dallas/Ft. Worth. The Atlanta as well as the Dallas/Ft. Worth databases are developed by Jeppesen. The databases have an accuracy of better than 1meter.

2.6 Jeppesen: FliteDeck

Jeppesen's FliteDeck is a moving map evolution of the JeppView product, and is a 2D depiction of the aircraft environment. Future versions of the FliteDeck products may include features such as: the display format changing in relation to the phase of flight. For surface movement operations, a detailed fully vectorized geo-referenced airport database could be used. The pilot sees their own aircraft taxiing over the airport surface (see Figure 8a). The airport and navigation data symbology is compliant with the conventional Jeppesen paper charts. The major advantage of such an approach is that pilots are familiar with the symbology and do not have to adapt to new paradigms.



a.) b.) c.)

Figure 8. Jeppesen Moving Airport Map (a) Moving Map Approach Chart (b) En-route Moving Map (c)

A prototype next generation of this product could support the following: While the aircraft approaches an airport, conventional 2D navigation data is shown (see Figure 8b). In addition, contour lines of the surrounding terrain are rendered to improve terrain awareness. Dangerous terrain in front of the aircraft would be shaded in red.

During the cruise phase, a vertical profile of the flight plan and the current aircraft position above the terrain could be shown (see Figure 8c). Weather information (with standard Jeppesen weather charts) and other aircraft (with TCAS symbology) can be overlaid as well. The cruise display can also be used for flight planing.

A key advantage of the such a design is that pilots are familiar the symbology. Almost no new symbology is introduced. Pilots do not have to get acquainted to any new flight symbology or metaphor. Other SVD are the Honeywell 3D EPIC display[13], Prof. Sachs 3D display[20], and Jorj Baker's Free Flight GA 3D display[6]. There are also a number of Industry Committees that are working on standards for MFD and the associated information rendered upon them, most notably the SAE G-10 group, which is itself separated into a number of sub-groups of interest

3. DATABASES

Today's use of databases in cockpits is limited to Commercial Transport Aircraft with Flight Management Systems (FMS) or Terrain Warning and Alert Systems (TAWS). Currently, these devices use individual proprietary data in very low resolution displays[12]. In contrary, next generation SVS with high quality renderings will be most likely first introduced into GA aircraft.

Depending on the SVD applications different data sources have to be selected. In general these are terrain, airport, obstacle, and navigation data. These data sources are divided in two logical groups[4]. Flight critical data must be very reliable and highly accurate because it is used as primary or sole means of navigation. In advisory data source inaccuracies can be tolerated if they cannot be removed from the data source. They only provide additional information cues to a pilot. For GA-SVS terrain, airport, and obstacle data are considered as advisory data. In this paper it is assumed that with SVS the operational envelope for GA will not be extended in the next few years. Neither currently available navigation reliability for

GA, nor available database accuracy will enable this. The short term goal is not to fly VMC under IMC. Instead, SVS in GA aircraft will increase safety by improving pilot situational and positional awareness in mountainous terrain and on the airport surface. SVS is also a powerful tool for pilot familiarization with new airports, approaches, and new procedures.

3.1 Terrain and Obstacle Data

Digital elevation model (DEM) data is a key component for SVD. DEM's for SVS can be created at a high accuracy levels. There are several different satellites generating terrain models. For example SPOT-Image, Landsat-TM, European Research Satellite (ERS)-I-II, and Ikonos 2. The Shuttle Radar Topography Mission, (SRTM), generated a high resolution (30m) terrain model collecting data from 56° South to 60° North. In 2002 at the earliest, the processed 30m data will become available in limited distribution to authorized organizations. It is not yet clear to what extent will obstacle data be collected as well. All these DEM are generated with different acquisition methods and independent sensors. These independent models enable data validation and future certification[4]. For validation and to estimate the terrain database error, comparisons among all databases and usually with a high precision data source is performed. The result are database differences (see Figure 9). The highest overall altitude for a given coordinate is taken. A reliability value is given by the maximal differences among the different databases. The Figure below shows such as comparison. In flat terrain marginal differences are found but in mountainous areas models vary significantly.

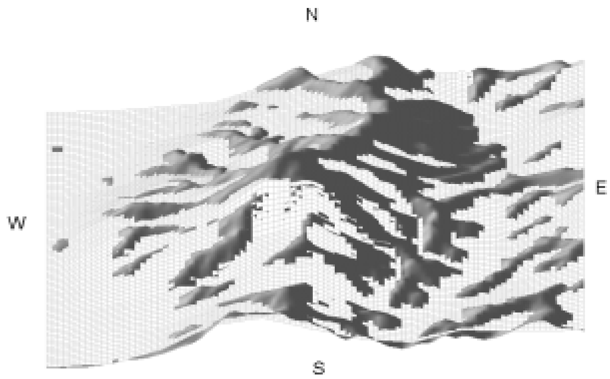
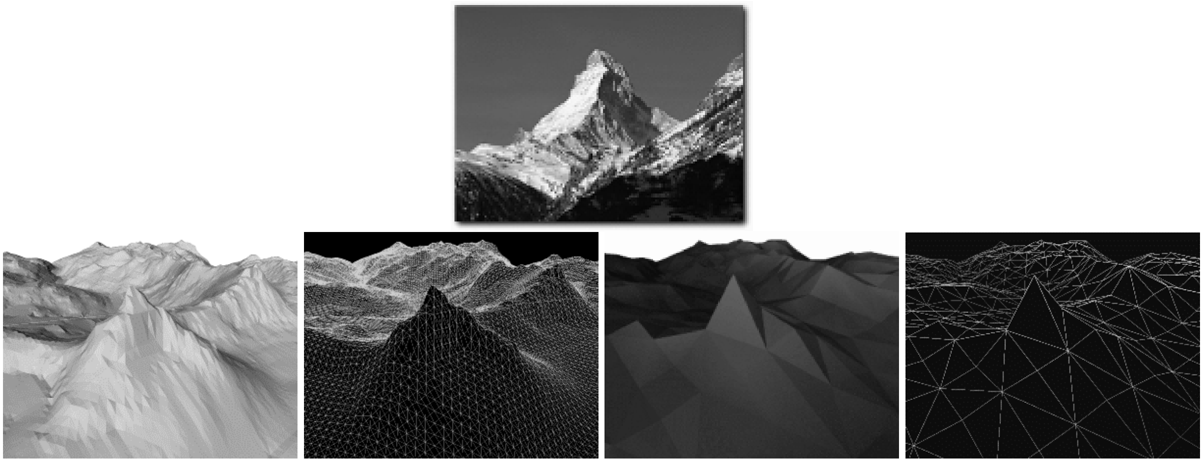


Figure 9. DEM comparison (differences are visualized)

It must be remarked that to retain the pilots confidence in the SVD it is highly recommended that the terrain has the maximal possible resolution. Figure 10 shows two DEM of the Swiss Mattherhorn. The 90m (3") DEM faithfully represents the mountain. In the 1km (30") model the summit is 400m too low and the mountain flanks are significantly lower than in the 90m DEM.



(90m original DEM) (1km original DEM)

Figure 10. Airport Database Generation

World-wide terrain data is already available. It is processed as above described. For aviation applications DEM data is sold by commercial vendors such as Jeppesen-Sanderson, Inc. in Denver or Advanced Information Systems (AIS) in Germany.

3.2 Airport Creation

Threshold, taxi-line, and parking position data to an accuracy of 0.5-1m is required by ICAO Annex 11 and 14. Few countries are completely compliant with these ICAO requirements. The consequence is that SVS-required geo-referenced airport data is unavailable[25]. However, non geo-referenced vector data for runways, taxi-ways, taxi-lines, and parking areas is world-wide available in Jeppesen vector airport diagrams[23]. The data can be geo-referenced to available threshold and stand coordinates[23]. The resulting database enables principal SVS taxi operation on an airport. Jeppesen is currently evaluating providing such geo-referenced airport charts in the near future.

In the future, high resolution databases from all airports can be gathered from aerial photography or satellite imagery[25] (see Figure 11). The imagery can be geo-referenced to WGS84 coordinates. From the geo-referenced image the airport can be digitized and a 2D vector model generated[25]. Finally, the model can be enhanced to a 3D database and stored in a hierarchical data format[25]. Figure 11 shows the principal processing of airport data.

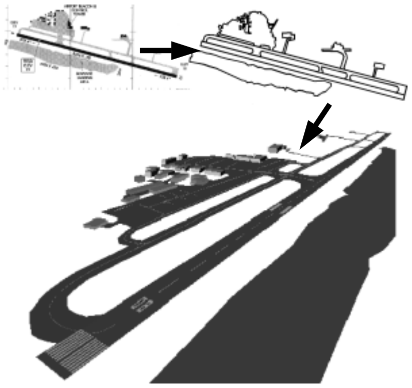


Figure 11. Airport Database Generation[4]

Required Navigation Precision (RNP) analysis for airports shows that the required database accuracy is in the 1m range on a 95% level[15]. With the above described photogrammetric surveying technique these requirements can be fulfilled[25].

For the verification of airport databases no complete local surveys are needed. Only some control points have to be measured by D-GPS survey. These control points can be correlated with the generated database.

Currently, RTCA-SC193/EUROCAE WG41 sub-group three defines required database contents such as: thresholds, runways with all markings and supplemental runway information (e.g. threshold displacement, landing distance, take-off distance), taxiways with taxi-lines, stop-bars, heli-pads, apron areas with stands, parking positions, and airport related obstacles. All data shall be in three dimensional spherical WGS-84 coordinates. As recommended supplemental data noise abatement zones, airport roads, and restricted areas are seen. All provided data shall be accurate to 0.5-1m level on a 95% confidence level. These quality requirements are coherent to ICAO Annex 11 and 14. All updates are supposed to be integrated into a database within 56 days. Prior to the incorporation it is assumed that changes are published as NOTAMS. The data originator has to provide data origin and data processing information. Also an Geographical Information System (GIS) based open airport exchange format is proposed by RTCA-SC193/EUROCAE WG41.

3.3 Database Concept

The previously described data generation processes ensures availability of data and defines general exchange formats. However, these databases are not directly usable for SVS. For world-wide applications these databases are huge and cannot be directly taken into an aircraft. In addition, a SVD needs to render a 3D perspective image of the database in real-time at about 15 to 30 frames/sec[5]. Today's graphics engines cannot load, store, and render the above described raw data-sets in real-time because of their storage formats and content density. In order to overcome these problems a three step process is proposed (see Figure 12).

In the first step all needed data sources are integrated into a High Quality Database (HQ-DB). This HQ-DB contains all needed information for a world-wide SVS application. Selected data is then converted into the Real Time Onboard Database (RTO-DB) allowing real-time storage and rendering in an aircraft. The RTO-DB can be taken into an aircraft and the

Database Sever (DB-Server) selects appropriate database regions (tiles) from the RTO-DB. The DB-server also processes short-term updates taken from a data-link. It hands the final database to a SVD.

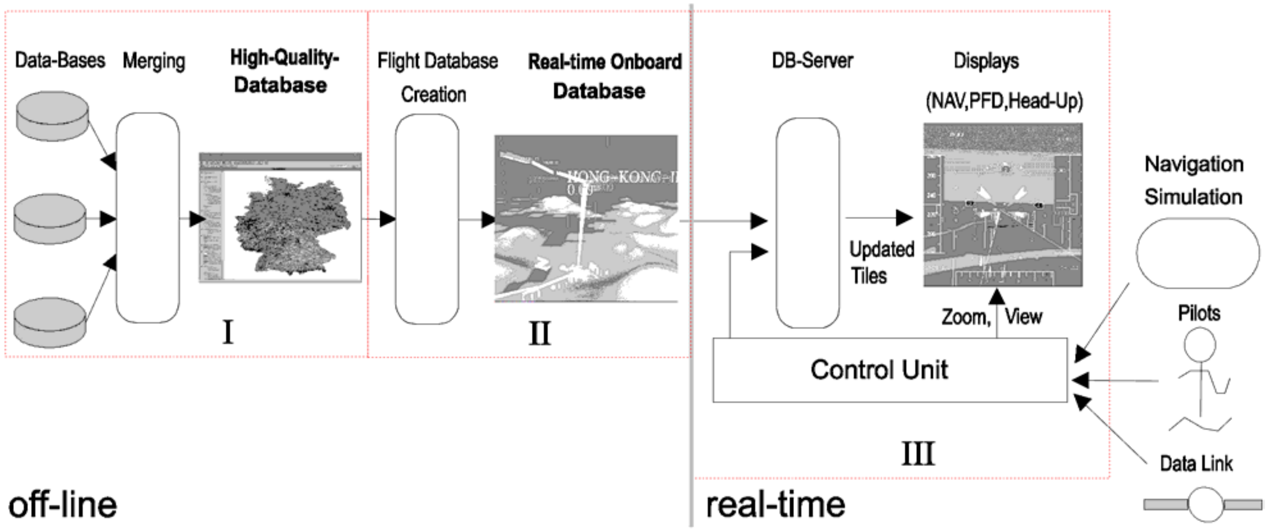


Figure 12. Three Step Data Processing[4]

3.3.1 High Quality Database Creation

The HQ-DB is stored and handled with a commercial Geographic Information System (GIS) (see Figure 13). A GIS handles and merges large databases as they are required by world-wide applications[3]. With a GIS principal consistency checks on the database can be conducted. For instance, it can be pre-checked whether or not airways intersect terrain or if a given airport is located under the terrain[4]. In Figure 13, Jeppesen stores in a HQ-DB world-wide terrain, navigation data, and several completely geo-referenced geo-spatial airport databases.

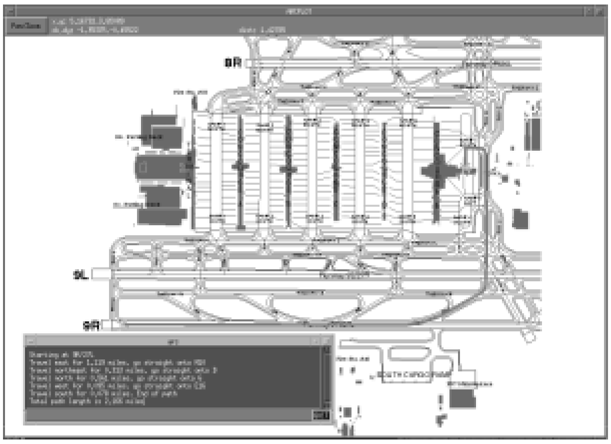
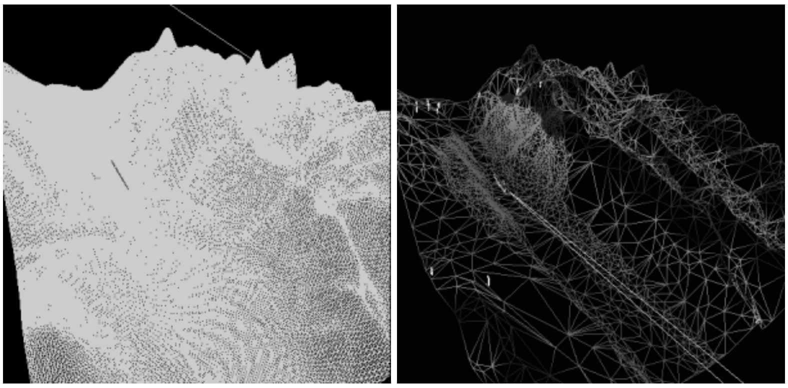


Figure 13. Jeppesen HQ-DB showing Atlanta, GA

3.3.2 Real Time Onboard Database Creation

The HQ-DB cannot be handled by a SVS due to rendering speed and memory limitations. To overcome this problem a RTO-DB creation process is established by Darmstadt, University of Technology[3]. The data is converted into a real-time capable graphics format called Open Inventor[4]. Inventor can be read by most graphics tools such as Multigen or EasyTerrain. It is also directly usable as Virtual Reality Markup Language (VRML) files in a World-Wide-Web (WWW) browser visualizations.

The DEM data contains most polygons and consumes most amount of disk space. Therefore, DEM data must be compressed and simplified by data reduction[21]. On the airport no error is tolerated. Close to published approach paths and in the vicinity of the airport up to 10m errors are accepted. Out of airports the terrain is reduced to a maximally 50m error. For faithful terrain representation raw data with a 90m (3") post-spacing is needed. Using the above specified error levels about 95% of the DEM data can be eliminated with the method proposed in[21]. Figure 14 shows the raw 90m DEM and the decimated model for Innsbruck, Austria. The resulting database can be rendered with up to 20Hz on a state of the art conventional Personal Computer (PC) graphics board.



(Original 90m data) (decimated model)

Figure 14. Terrain decimation for Innsbruck, Austria

3.3.3. Database Server

The RTO-DB can be taken into an aircraft. The DB-Server concept allows the system to handle the RTO-DB for real-time applications. Additional, NOTAM and Weather information can be incorporated and displayed to the pilot. The DB-server fetches appropriate database tiles and hands it to the graphics board.

3.4 Certification of Database Processing

Up to now only FMS navigation and TAWS terrain databases are used in airborne avionics systems.. Examples for TAWS are Dassault's Ground Collisions Avoidance System (GCAS) and Allied Signals Enhanced Ground Proximity Warning System (EGPWS). For the handling of terrain and navigation databases certification standards and procedures are already in place. RTCA-SC181/EUROCAE WG13 implemented DO-200A providing guidelines for the certification of database generation. For instance, Jeppesen currently plans to have a DO-200A certification for its navigation database generation. In addition, RTCA-SC193/EUROCAE WG41 defines data contents and quality requirements for airport, terrain, and obstacle databases. The underlying concept is to certify the data processing but not the database itself. A typical certification process for SVS databases is depicted in Figure 15.

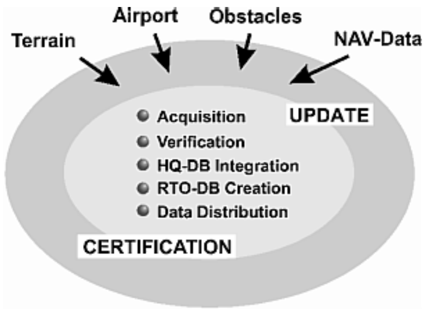


Figure 15. Database Creation Process[4]

The end-user himself (e.g. an airline or GA pilot) is liable for the quality of the data. The certification of the software used in the processing chain must be based on well established standards such as DO-178B, MIL-STD-498, DOD-STD-2167A and DIN-ISO 9000-3.

The major problem for the future is not the certification of data processing but the availability of unclassified high accuracy data. However, with the methods described above it is assumed that world-wide database will be soon available. It is the declared goal of companies such as Jeppesen to provide navigation, terrain, and airport data in the future to all kind of SVS applications.

4. NAVIGATION

Even though SVS for GA aircraft only contains advisory information the necessary position determination has to be reliable. The reason is that after pilots are acquainted to a SVD they trust the compelling depiction. Differential GNSS (DGNSS) is enabled through the US based WAAS and the European EGNOS. DGNSS has the potential to provide highest accuracy in kinematic SVS for low costs. It seems therefore be suited for GA. Research conducted during the NASA Atlanta trials shows that 95% of the DGNSS data had an error smaller than 1m[15]. The Stanford University research in Juneau, AK shows approximately the same results with WAAS augmentation[1]. DGNSS short-comings lie within the reliability[19]. Within a five year trial period on the Frankfurt airport researchers found 95% of the DGNSS data within the 1m error range. However, for the remaining 5% they encountered different problems[19,11]: The GPS signal was sometimes lost for several minutes because of jamming from other radio emitters nearby. The positional error slowly accumulated to over 100m while eight satellites were visible with a GDOP of two and an internal assumed receiver error in the sub-meter range. Finally, sometimes for over 30 minutes not enough satellites were visible at all. Therefore, they will investigate a combination of GNSS and Loran-C for low cost systems[17].

From the above results it can be concluded that DGNSS has adequate performance in 95% of the time, in 4.9% satisfactorily recognizes failures, and fails to detect unacceptable large errors in 0.1%. For supplemental GA SVS these results seem acceptable. For commercial transport aircraft SVS a hybrid navigation is needed. It must combine the advantage of DGNSS and board autonomous navigation sensors to achieve highly reliable precise navigation[18].

5. NASA AVIATION SAFETY PROGRAM

The SVS program within the framework of the NASA Aviation Safety Program (ASP) will focus on enabling technologies for SVS. Three different groups under the leadership of Rockwell-Collins, AvroTec, and Research Triangle Institute will develop SVD for commercial transport aircraft and GA.

Under the leadership of Jeppesen ADR-Marconi and Darmstadt, Univ. of Tech. will build three SVS databases. The databases will cover 5°x5° around Juneau, AK, Reno, NV, and an airport located in South America. As a key component to the future success of SVS the development of a certifiable process chain for database acquisition, verification, distribution, and update is determined. Therefore, industrial applicable procedures to certify aviation database processing will be proposed.

In flight trials all three generated test databases will be test flown with a GA (Jeppesen) and a commercial transport aircraft (NASA). The goal is to evaluate the SVD and the generated databases. Also the increase in situational awareness for GA and commercial transport aircraft pilots shall be demonstrate.

6. HARDWARE

One of the principal driving factors in the development of SVS technology has been the display sub-sytem technology. In the early generation of Electronic Flight Information Systems (known as EFIS), these were limited both in the types of graphic primitives that could be rendered in full sunlight readibility, and the number of colors was very small. The panel space required behind the flight deck to house the cathode ray tube (CRT) was significant, and these early units could not be used for SVS applications.

The most significant improvement came with the advent of Liquid Crystal technology, that soon evolved in the Active Matrix Flat Panel units that are being widely adopted by a number of manufacturers. These units are capable of displaying 256 colors or more, with graphics resolutions of 800x600 or higher, all in full sunlight readibility. Once the display unit could render the information, we now needed more computing power for the calculations, and then more graphics horsepower to drive the higher resolution (and more demanding from a bandwidth perspective). This need was also helped with the wider development of COTS processor units, using either Wintel® architecture, or 1553, or ARINC 429, or others. This increase in raw computing power, coupled with the advances in display technology, have made SVS a possibility today, without any further advances required.

7. CONCLUSION

SVS will be usable in the near future for all GA aviation pilots. The increase in data availability and accuracy, the improvement of navigation accuracy and reliability, and the increase in PC rendering power makes this feasible. The goal to enhance situational awareness by depicting terrain, airports, and other aircraft is reachable. The SVS development is not limited to commercial transport aircraft. In contrary, most likely GA pilots will be the first using SVS as the next logical step in the technological development.

8. ACKNOWLEDGEMENTS

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